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VIDEO DISPLAY FOR STUDY OF AVIAN VISUAL COGNITION: FROM PSYCHOPHYSICS TO SIGN LANGUAGE

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ABSTRACT: We demonstrated four different ways of using video systems for research in avian visual cognition: 1) recent developments of high vision TV systems made it possible to use the video system for psychophysical studies. Visual acuity measured with such a video system was comparable to those obtained by more traditional methods; 2) using image processing software, we could display unnatural animals, such as chimeras on the TV screen. We also reported that pigeons did not discriminate partially occluded conspecifics; 3) effects of exposure to visual stimuli upon on-going behavior were examined using suppression and conditioned suppression procedures; and 4) discrimination of moving images, namely two words of Japanese Sign Language, are reported.

Humans and most avian species are animals with sophisticated visual capacity. Ancestors of primates and that of birds might share some common ecological niche, namely jumping from tree to tree to find food and to avoid predators. Visual information processing is required for estimating distance from tree to tree and detecting something partly occluded by leaves. Comparative psychologists have shown not only psychophysical but also higher cognitive capacity in birds. Pigeons can discriminate many different kinds of natural categories such as humans, trees, leaves, conspecifics, food, paintings and so on (see Bischof and Zeigler, 1993, for a review of recent studies).

Since the research of Herrnstein and Loveland (1964), a slide projector has been the most common way of presenting complex visual stimuli. The slide projector is easy to control and allows fine resolution on a screen. However, the researcher has to repeatedly set slides into

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the carousel and modification of the photopicture, such as production of a chimera picture, is time consuming. Recently researchers have employed the TV monitor as a stimulus presenting device. Random access to a particular frame is easily carried out with a TV monitor connected to a computer and image processing software makes it possible to produce complex visual stimuli on the monitor screen. In this paper we demonstrated four different ways of using a video system for research into bird visual cognition, and finally discuss some problems associated with video display for animal research.

1. USE OF A VIDEO MONITOR IN PSYCHOPHYSICAL STUDIES

Many studies have measured visual acuity in birds using a slide projector as a stimulus presenting device. For example, Hodos *et al* (1976) reported that the visual acuity of the pigeon was 1.9 min of arc. A potential problem of using video monitors in psychophysical studies is limits resulting from the number of scanning lines and pixels. The NTSC TV system, the conventional TV system, has 525 scanning lines and 330000 pixels. The PAL TV system has 625 scanning lines. These limitations make it difficult to use such TV systems for psychophysical studies in which finer resolution is required. NHK, the national broadcasting company in Japan, has recently developed a new High-vision system. It has 1125 scanning lines and about 2 million pixels. Thus, the resolution is approximately five times greater than the conventional video system. We have employed this system to measure the visual acuity of the pigeon (Furuya, 1996). The bird was trained to locate its head at a specified position (as detected by a photosensor) in front of two circular pecking locations in which the stimuli were displayed on the TV monitor. The distance between the head position and the monitor screen was 16cm. When the pigeon located its head correctly, a horizontal stripe (width of 1.45 arc min) or plain grey pattern appeared on the screen. The mean brightness of the stripes was identical to that of the grey pattern (54 cd/m²). A peck on the screen produced a food reward when the stripes appeared, while no reward was given when the grey pattern appeared. Each training session consisted of 60 trials. If the birds responded more than 80 percent correctly, the stripes were changed to finer ones in the next session.

Figure 1 shows examples of the results. The visual acuity of B12 was between 3.9 - 5.6 min. and for C14 was 3.9 min. Hodos *et al* (1976) reported a minimum acuity threshold of 1.9 min at a luminance

of 214 cd/m². However, at luminance levels comparable to the present study (54 cd/m²), the brightness-acuity function shown by Hodos *et al* (1976) shows a visual acuity of approximately 3 min. Thus, the visual acuity measured by the video system is close to that measured using projected gratings and a slide projector.

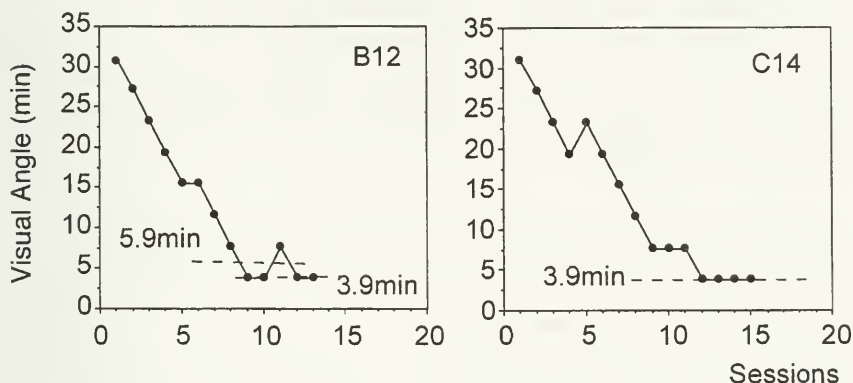


Figure 1. Example results of the visual acuity test. The stripes become finer when the subjects achieved more than 80 percent correct.

2. MODIFICATION OF THE VISUAL STIMULUS

A TV monitor has also been used for the presentation of more complex stimuli, such as images of conspecifics for pigeons (Watanabe, 1992) and chickens (Evans and Marler, 1991) or jumping spiders (Clark and Uetz, 1990). Development of imaging processing software makes it also possible to modify the visual stimuli. Thus, we can produce biologically impossible chimeric images of animals, such as a pigeon with a hawk head. Watanabe & Jian (1993) trained Bengalese finches to discriminate between individual conspecifics using a still video player (Konica KP-400). During discrimination training, still images of the birds were displayed on a TV monitor in conjunction with the sound of contact calls.

After the subjects learned the discrimination, the image of finch A was presented with the calls of finch B and the images of finch B were presented with A's calls to determine whether visual or auditory cues controlled the discriminative behavior. The results demonstrated that the visual cue was dominant. Then, we made a chimera image of A's head with B's body and vice versa using image processing software

(Adobe Photoshop). When, we presented these chimeric stimuli, some of the subjects showed discrimination by contact calls. That is, when the normally dominant visual cues did not give enough information, the finches employed auditory cues for individual discrimination. Brown and Dooling (1993) reported that the patterns of stripes in the face was the most salient visual recognition feature for budgerigars.

We then analyzed recognition of conspecifics in pigeons in the following two experiments. The first involved detection of a partly occluded conspecific, and the second was discrimination between a pigeon and a starling.

EXPERIMENT 1: DOES THE PIGEON SEE A HIDDEN BIRD?

Cerella (1980) reported that pigeons could not discriminate a hidden triangle if presented as shown in Figure 2. However, a triangle is probably an unfamiliar stimulus for a pigeon. We wanted to know whether a pigeon could discriminate an image of another pigeon when that image was partially occluded, ie., would the birds perceive a hidden pigeon rather than just a part of one.

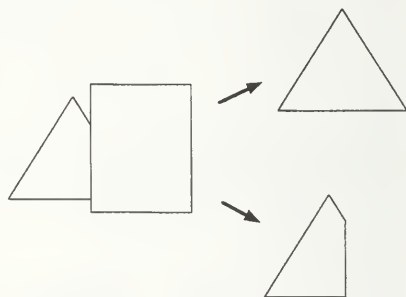


Figure 2. Occlusion of a triangle. Humans can see the occluded triangle shown on the left.

METHOD

Subjects

Eleven experimentally naive pigeons were used. They lived in individual individual cages made of stainless wire mesh (30x34x35cm). Water and minerals were freely available but access to mixed grain was restricted to maintain about 80 percent of their free feeding weights. Illumination of the animal room was kept 12L:12D cycle artificially.

Apparatus

An operant chamber (30x30x30cm) with a transparent rectangular pecking key (10x7.5cm) was used. There was a TV monitor just behind

the pecking key. The image appeared on the TV screen connected to a laser disk player (TEAC,LVA2000).

Procedure

All pigeons were trained to peck the TV screen by an autoshaping procedure, and then were trained on a Variable Interval (VI) 30 sec schedule. The subjects were then divided into two groups. The "head" group received discriminative training between an image of a pigeon's head above a grey board and the grey board without the head, and the "body" group between an image of pigeon's body under the board and the board without the body (Figure 3). Response to the stimulus with a part of a pigeon was reinforced on VI30 sec while that for the plain board was extinguished in each group. One discriminative training session consisted of 40 random presentations of two stimuli, each lasting 30 sec separated by a 5 sec blackout period. This training continued until the subject showed a discrimination ratio of more than 90 percent, calculated by dividing the number of responses to the stimulus associated with reinforcement by the total number of responses to both stimuli, for two successive sessions. They the received a test with the original images, a whole image of a pigeon and part of the pigeon. These stimuli were presented randomly five times each. No reinforcement was given during the test. If pigeons saw a hidden bird behind the board, they should have responded more often to a complete bird than to the original stimulus. On the other hand, if the pigeons attended to just a head or a body, they should have responded to the test stimuli non differentially.

RESULTS AND DISCUSSION

Figure 3 presents the results of the two groups. The subjects learned the discrimination tasks in approximately 20 sessions. The response to each test stimulus was expressed as a relative response to that emitted by the original stimulus. The subjects trained to peck to the "head" above the board responded more often to the original stimulus, to the whole image of a pigeon and to the head of the pigeon than to the board ($F(3,16)=18.3, p<0.0001$). There was no statistically significant difference between responses to the three stimuli containing part of a pigeon, while the response to the plain board was significantly less than that to each of the other stimuli ($p<0.001$ for each stimulus

pair, Fisher's PLSD).

The subjects trained to respond to a pigeon's "body" under the board also showed a similar tendency. They pecked often at the original, the whole body and body part of the pigeon $F(3,20)=10.27$, $p<0.0005$). There was no statistically significant difference among the three stimuli containing the pigeon's body but a significant difference between the plain board and the other stimuli ($p<0.001$ for each pair, Fisher's PLSD).

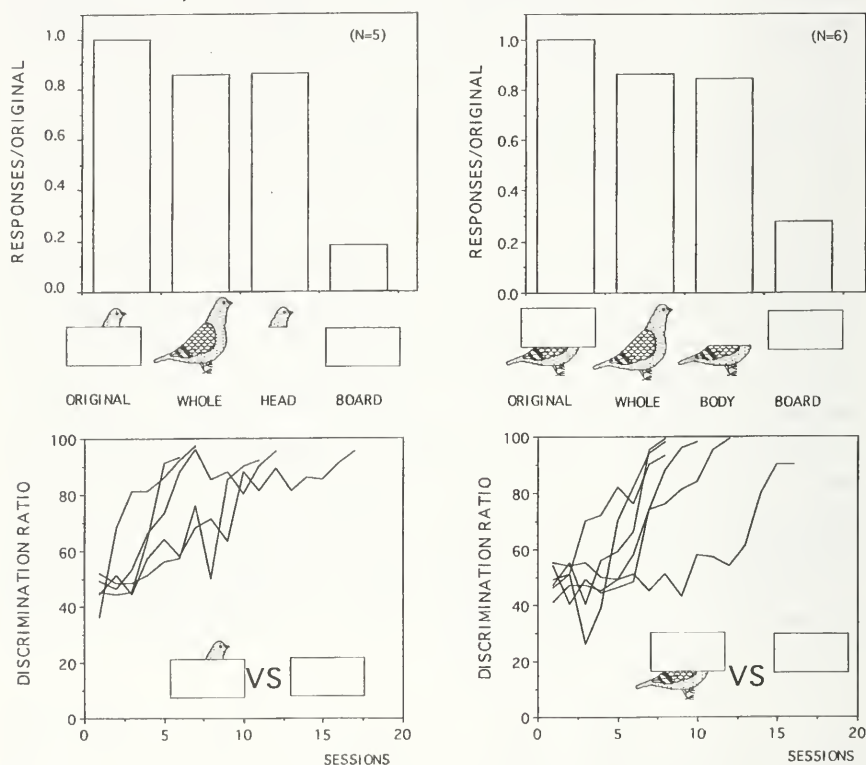


Figure 3. Results of the hidden bird discrimination. The lower two panels show individual discrimination learning curves of the "head" group (left) and the "body" group (right). Upper panels show the mean results of the tests.

These results suggest that the presence of a part of the pigeon is enough to control the subjects' discriminative behavior. The responses observed in the present experiment are considered as similar to the phenomenon of "feature positive" discriminations (Jenkins and Sainsbury, 1970). In GO/NOGO discrimination training, it is easier to learn to respond to a stimulus with an added feature than to learn to respond to a stimulus without the feature. This phenomenon has been

well demonstrated with many species including humans. The feature, in this case the head or the lower half of the body, controlled the discriminative behavior. In other words, the subjects did not complete the partly occluded pigeon. This finding confirms earlier reports by Cerella (1980) and Sekuler *et al* (1996) in which geometric figures were used as stimuli.

EXPERIMENT II: CUES FOR SPECIES DISCRIMINATION

Testing with chimera stimuli has also been used to analyse the discrimination of complex stimuli (Lea and Ryan, 1990; Cook *et al*, 1990; Brown and Dooling, 1993). Using a slide projector, we trained pigeons to discriminate between the heads of two conspecific individuals (Watanabe and Ito, 1991). We then cut and pasted parts of printed photographs of the birds to make chimera slides. The results of tests with such chimera stimuli suggested that there was no single cue for the individual discrimination.

Recent image processing software can easily produce similar types of modified stimuli. In the present experiment, pigeons were trained to discriminate between visual images of a pigeon and of a grey starling. Subsequently, responses to two different kinds of modified images were examined; one involved the exchange of facial parts, such as a chimera, and the other involved morphing of two images.

METHOD

Subjects

Four experimentally naive pigeons were used. They were maintained at 80 percent of their free feeding weights.

Apparatus

The apparatus used in the experiment 1 was used.

Procedure

The apparatus and methods were similar to those used in experiment 1 except for the stimuli. The subjects were divided into two groups of two. For one group (pigeon group), an image of a pigeon's

head was used as the stimulus associated with reinforcement while an image of a starling's head was used as the stimulus not associated with reinforcement. The other group (starling group) was trained on the reverse task, that is, the starling was the positive stimulus and the pigeon was the negative one. After the subjects learned the discrimination task, they were tested with two series of stimuli. The first series involved exchanging parts of the two images. Thus the birds were exposed to the original image, or this image but with a beak or eye or feathers of the other bird. One test consisted of 5 presentations of these stimuli each lasting 30 sec separated by a 5 sec blackout period. No reinforcement was given during the test.

The second series involved morphing. A photoshop morphing program was used to produce the testing stimuli. Twenty positions were selected as feature points on the images and the program then mixed the shape and color of these corresponding points at 20, 40, 60, and 80 percent mixing rate (Figure 4). One test consisted of 6 presentations of these six stimuli, including the original pigeon and starling, and each presentation was 30 sec separated by a 5 sec blackout period. Again no reinforcement was given during the test.

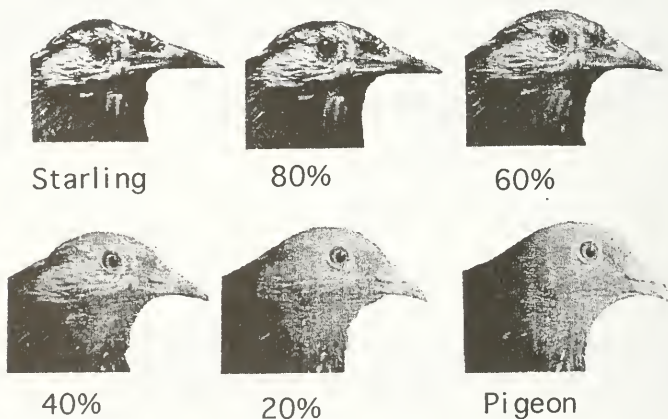


Figure 4. Stimuli produced by morphing. The top left is the original 100 percent starling and the bottom right is the original 100 percent pigeon.

RESULTS AND DISCUSSION

Figure 5 shows the results. Two birds, one in each group, learned the task in 5 or 6 sessions. Other two needed more than 25 sessions.

Responses to the chimera stimuli were expressed as a percentage of the number of responses to the original stimulus. As shown in the figure, the exchange of beak or eyes did not greatly depress responding. On the other hand, exchange of the feathers had a more severe consequence. This might be because the starling has distinctive white feathers on its cheek and the subjects used this feature for the pigeon vs. starling discrimination. In other words, they did not need a complete image to detect the discriminative stimuli.

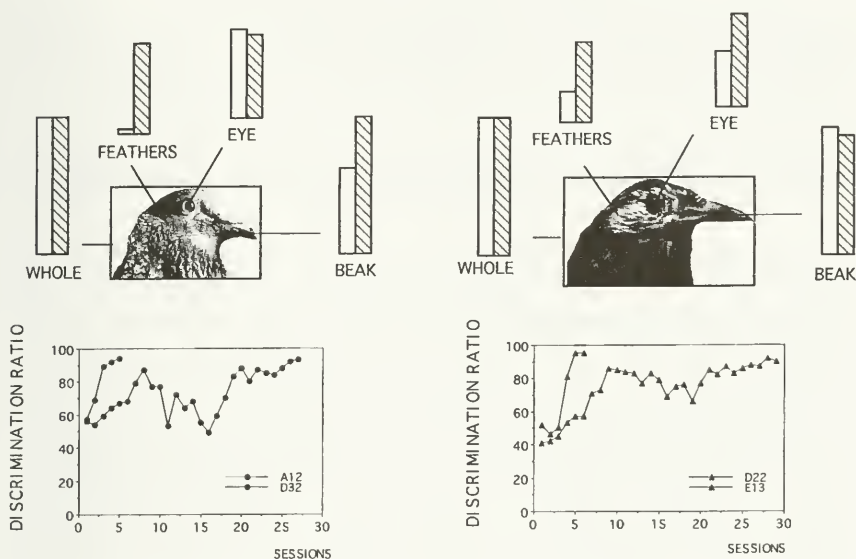


Figure 5. Results of the conspecific discrimination. The lower panels show individual learning curves of pigeon positive (left) and starling positive (right) discriminations. The upper panels show individual results of the whole or body part (feathers, eye or beak) exchange test - for example, "Eye" in the left panel means the responses to the image of a pigeon with the eye of starling by two separate subjects.

Figure 6 presents results of the morphing test. The birds were able to discriminate the images when the mixing rate was 80 percent. One bird trained to respond to the starling discriminated the starling within the 60 percent picture. Morphed images were not only determined by mixing rate but also by the number and the locations of feature points. Thus, the critical mixing rate at 80 percent found in this experiment is not a general rule of morphing discrimination and further research using a wire-framed model or other well defined model will be necessary to obtain conclusive results.

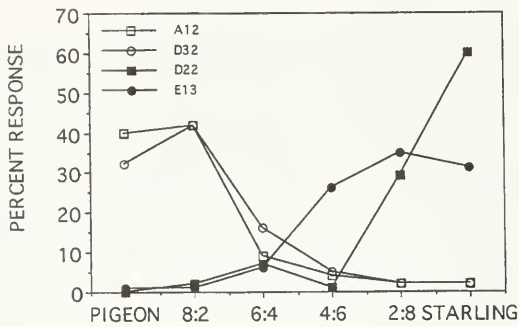


Figure 6. Mean results of the morphing generalisation test. The extreme left and right are the complete pigeon and the complete starling respectively.

3. SUPPRESSION OF OPERANT BEHAVIOR BY VISUAL STIMULI

The experiments described above used still images. The other type of stimulus is a moving stimulus. Evans *et al* (1993) has shown that computer-generated animation simulating aerial predators elicited alarm calls in chickens. Jungle fowls exhibited social facilitation of feeding when exposed to videotapes of conspecific feeding (Mcquoid and Galef, 1993). Chickens produce alarm calls more frequently when other conspecifics are presented. This facilitative effect is called an audience effect. Videotapes with sound were more effective in producing audience effects on alarm calling in chickens (Evans and Marler, 1991). Display of moving images may suppress ongoing behavior.

Pollution by pigeons is a major problem in big cities such as Tokyo. Contamination by defecation and nesting is particularly serious in railway stations, temples and in big apartment buildings. Therefore, it is important to deter pigeons from populated areas. A loud noise or other aversive stimulus is not suitable in areas where people are living. Thus, if some visual stimulus was shown to deter pigeons, it could be a convenient tool to control their behavior. In fact, there are several commercially available visual stimuli designed to deter birds, such as a balloon with a big eyeball. However, the effects are not permanent.

We tried to find such a visual stimulus (Furuya and Watanabe, 1996). At first pigeons were trained on a Variable Interval 60 sec schedule in a conventional operant chamber. After the subjects showed a steady response, moving images were displayed on a side wall of the operant chamber (25x30 cm) with a video projector.

The stimuli were made by a screen saver program and recorded on

a video tape. Three different stimuli were made, namely a rotating eyeball (diameter 95mm), frost and fire (10 - 250 cm in diameter), and a flying bird (52x29mm). These tapes were played back continuously and an electromagnetic shutter connected to the video projector controlled presentation of the stimulus. The stimulus appeared at 5 min intervals for 1 min. One session lasted 30 min. The suppression ratio was calculated by dividing the number of responses emitted during the stimulus presentation period by the number of responses recorded during a 1 min period immediately before the stimulus presentation.

One stimulus appeared until the subjects showed less than 10 percent suppression ratio. A conditioned emotional response procedure was then administered, that is, the presentation of the stimulus was followed by a brief electric shock (0.3mA, 10msec) through a grid floor for one session. After one session of conditioning, the stimulus appeared without electric shock in the following sessions.

Figure 7 presents an example result of such an experiment. This bird showed suppression of operant responding when exposed to new stimuli, but the suppression rapidly disappeared upon repeated presentations. Two possibilities have to be pointed out about suppressive effects of the visual stimuli. In this experiment all stimuli were projected on the side wall. Projection on the ceiling of the chamber may produce different results, because birds usually see aerial predators overhead. The frost and fire was selected from the screen-saver software because it has a most striking effect for human observers, but other patterns may more effective for pigeons. The electric shock suppressed the response again and this time, the effect continued longer than the previous exposure. There is, however, no significant difference among the types of stimuli.

These results suggest that it is difficult to deter pigeons for a long time using a visual stimulus alone and that pairing of the visual stimulus with an electric shock lengthens the aversive deterrent effect of the visual stimulus.

4. DISCRIMINATION OF MOVING IMAGES

Many animals use complex movements, such as dance display, as releasers. Therefore, they can discriminate complex movements at least in the case of fixed action patterns. Watanabe *et al* (1993) trained Bengalese finches on the discrimination of moving video images of two individuals. Two of four finches learned the discrimination and showed

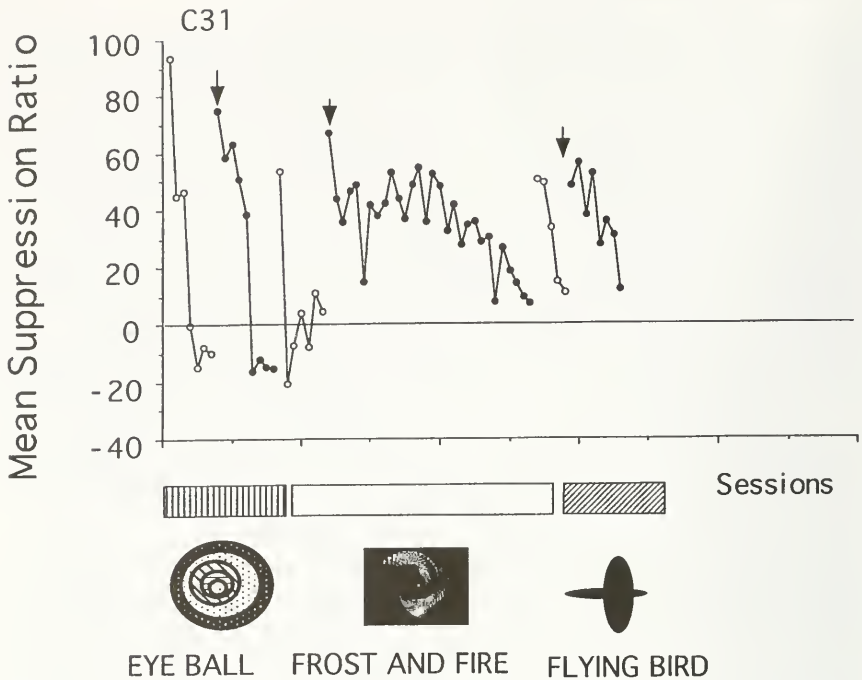


Figure 7. Suppression of operant by visual stimulus. Arrows indicate an electric shock session.

transfer of the discrimination from the moving images to still images. Although pigeons do not show any social behavior to life-size moving video images of conspecifics (Ryan and Lea, 1994), they can discriminate movements of a conspecific on a video display (Dittrich and Lea, 1993). Dolphins and sea lions also discriminate instructions made from a combination of movements by the trainer (Gisner and Schusterman, 1994; Herman *et al*, 1990; Shyan and Herman, 1987). There may be species differences in the perception of moving images or differences in perception may depend on the procedures. In the following experiment we tried to train pigeons to discriminate movements used in human sign language.

EXPERIMENT III: DISCRIMINATION OF JAPANESE SIGN LANGUAGE WORDS BY PIGEONS

Gardner and Gardner (1969) reported that chimpanzees can learn American Sign Language to communicate with people. In the present experiment, two pigeons were trained on a discrimination between two

words of Japanese sign language.

METHOD

Subjects

Two pigeons were used. They were maintained at about 80 percent of their free feeding weights.

Apparatus

The experimental apparatus was identical to that in Experiment I.

Procedure

We trained pigeons to discriminate between two words of Japanese Sign Language. One is "Japanese" and the other is "pigeon". The duration of movement of each word was 2 sec. Repeated demonstration of these words by a particular person was recorded on a laser disk and displayed on a TV monitor. Pecking responses to the screen were reinforced when one word ("pigeon") appeared on it, while pecking was extinguished when the other word ("Japanese") appeared. One stimulus presentation period was 30 sec followed by a 5 sec blackout period. This training continued until the subjects achieved more than a 90 percent discrimination ratio for two successive sessions. They then received three tests. The first was the reverse play test in which two movements were displayed in reverse, i.e, from the end to the beginning. The second was the still image test in which five postures of each word were selected and these still images were displayed instead of moving images. The third was a transfer test in which the two words demonstrated by a novel person were displayed. No reinforcement was available in these tests. The subjects received training sessions between the tests to maintain their discrimination.

RESULTS AND DISCUSSION

One pigeon learned this discrimination task within 30 sessions but the other bird required more than 85 sessions (Figure 8). The birds clearly discriminated the two movements when they were displayed in reverse. They maintained the discrimination even when still images

were displayed, but they failed to discriminate the words when they were demonstrated by a new person. Thus, the pigeon did not learn the concept of a sign language word but rather learned discrimination of the movement of a particular person.

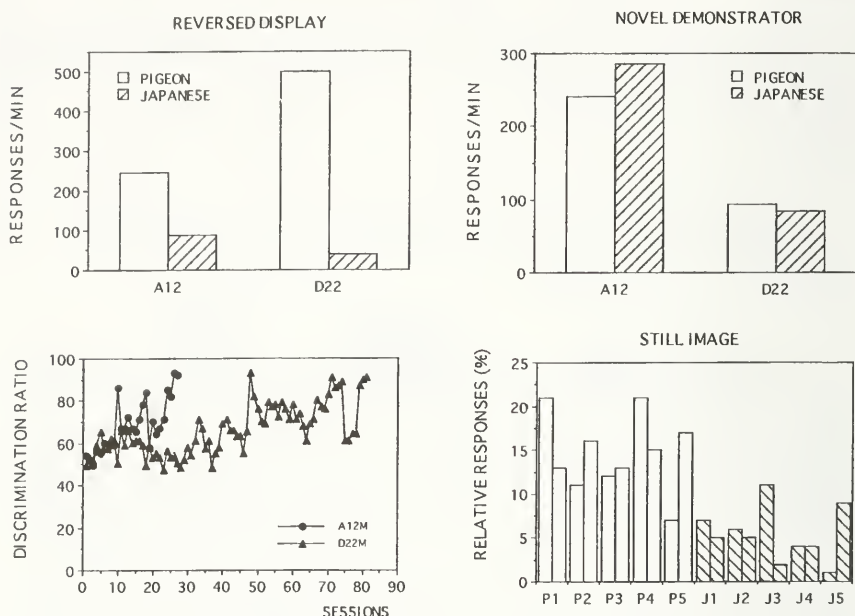


Figure 8. Discrimination of the sign language for the words "pigeon" and "Japanese". Lower left: learning curves of two subjects; lower right: mean results of the still image test. "P" and "J" indicate postures selected from movements of "pigeon" and "Japanese" respectively. Upper left: test of reverse play back. Upper right: test with a novel demonstrator.

Dittrich and Lea (1993) trained pigeons to discriminate video images of a moving pigeon and a still pigeon, and found generalization to movement of novel birds. This observation suggests that pigeons can form a concept of motion. Using a live pigeon as the discriminative stimulus, Millard (1979) succeeded in training pigeons to discriminate responding patterns of conspecifics. Furthermore, the pigeons showed generalization to the responding patterns of a novel stimulus bird. Pigeons can recognise social behavior of other pigeons in natural settings, so they should recognize a particular movement regardless of which bird displayed it. Although their social behavior may have more

distinctive features than in our Japanese sign language stimuli, the present results together with other previous studies suggests that pigeons' ability to discriminate movement is specialized to the movement of a conspecific. Recently, we trained pigeons on Johanson's stimuli discrimination, that is, movement of a few dots pasted on a pigeon's body (Oomori and Watanabe,1996). The birds learned to discriminate the movement of three dots pasted onto an a live pigeon from the movement of those pasted onto a toy dog. However, they did not show transfer of discrimination from movements of dots to real movement. Thus, they did not perceive the movements of these three dots as the movement of a real bird.

GENERAL DISCUSSION

One important point to consider in video display is the CFF (critical frequency of fusion). The scanning rate of a TV screen is 60 Hz, even in the Hi-vision system. Powell (1967) reported that the CFF for pigeons was 145Hz at a brightness of 100000 cd/m², and 100Hz if the brightness was reduced to 100 cd/m². Figure 9 shows the CFF curve calculated from the data of four subjects reported by Powell (1967). The average brightness of commercial TV is around 60-70 cd/m² and an extrapolated value of the CFF at this brightness is 58

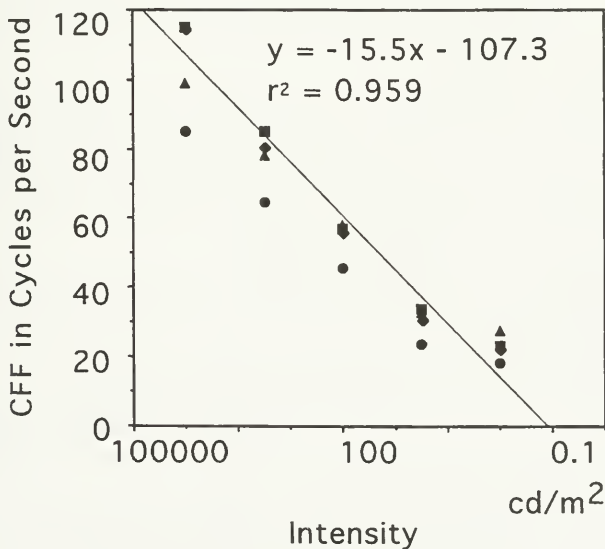


Figure 9. Relationship between stimulus intensity and critical flicker fusion calculated from data presented by Powell (1967).

cycles per sec. Thus, the high CFF in pigeons may not be a crucial disturbing variable if the brightness of the screen is dim.

Another critical problem is the discrepancy between the color system of a TV and the avian color system. The avian retina contains at least four different photopigments, while a color TV system is based on a mixture of only three components. Spectral sensitivity of the pigeon is also very different to human spectral sensitivity. Because TV systems produce color matched to the human color system, we can see rather natural color on TV but pigeons may not. TV systems are adequate for some monochromatic image studies but comparison of natural color and TV color is open for further research.

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SPACED-TRIAL OPERANT LEARNING WITH PURELY INSTRUMENTAL CONTINGENCIES IN PIGEONS (*COLUMBA LIVIA*)

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ABSTRACT: The purpose of this experiment was to study persistence during extinction of key pecking performance in pigeons (*Columba livia*) after training with either a large (15 food pellets) or a small reward magnitude (1 food pellet). Strictly instrumental contingencies were enforced and a single trial per daily session was administered. There were 52 acquisition trials followed by 48 extinction trials. Although extinction started from similar response levels in both groups, the pigeons trained with 15 pellets exhibited significantly slower extinction than those trained with a single pellet. This result is discussed in the context of comparative research on the effects of reward magnitude and schedule on extinction in vertebrates.

Pigeons can be trained to peck at a key for either a small (1 pellet) or a large reward (10 or 15 pellets, depending on the experiment) when practice is administered at a rate of a single trial per daily session (Papini, 1997). The main outcome of a series of experiments based on such a procedure was that extinction of key pecking was faster after acquisition with the small reward, rather than with the large reward. This type of behavioral adjustment to extinction is referred to as nonparadoxical performance. Such a result is interesting from the comparative point of view because nonparadoxical performance is typical of fish, amphibians, and reptiles, but not of mammals trained under analogous conditions (Bitterman, 1975). Mammals show paradoxical performance, that is, the successive negative contrast effect and the magnitude of reinforcement extinction effect (Amsel, 1992; Bitterman, 1975), under analogous training conditions (i.e., spaced-trial training with different reward magnitudes). In the case of contrast,

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mammals shifted from a larger or more preferred reinforcer to a smaller or less preferred one exhibit a deterioration of instrumental performance beyond the level of a control group always trained with the smaller or less preferred reinforcer. In the case of the magnitude effect, extinction is faster after training with a larger reinforcer, than after training with a smaller one. These results are paradoxical in the sense that they are not predicted by classic theories based on the hypothesis that associative strength is a direct function of reinforcer magnitude (Amsel, 1992).

The key-pecking experiments with pigeons have involved a relatively wide range of conditions; still, the results may depend upon some aspect of the training procedure, rather than on the species. For example, Roberts, Bullock, and Bitterman (1963) reported greater resistance to extinction after widely spaced training with partial reinforcement than with continuous reinforcement, a paradoxical effect thought to be related to contrast (Amsel, 1992). One major difference between Roberts et al.'s study and Papini's experiments is found in the nature of the reinforcement contingencies involved in each case. Roberts et al. used a runway procedure in which pigeons either responded in every trial, or were gently guided toward the goal box if they failed to initiate a response. As a result, the outcome of each particular trial was preceded by running, the target response in the experiment. By contrast, the operant procedure imposed a time limit for key-pecking, so that if the pigeon failed to respond within that interval, the scheduled outcome occurred and the trial was terminated. Although Papini (1997) showed that relatively few acquisition trials ended without the occurrence of key-pecking (the target response), this procedure introduces a response-independent outcome component that could have caused nonparadoxical extinction performance.

In the present experiment, a series of 10 key-pecks were paired with either 1 pellet or 15 pellets in independent groups during acquisition training. Failure to complete the fixed-ratio (FR) 10 requirement within a maximum time resulted in the termination of the trial and the withholding of the reward. This procedure is therefore referred to as purely instrumental in the sense that the reinforcing event only occurred when the animal satisfied the response requirement within a time limit.

METHOD

Subjects

Twelve pigeons, all sexually mature and obtained from a local dealer, served as subjects. Animals were housed in individual wire cages. Water and grit were continuously available in the cage, but food was restricted to keep animals at 75% of their ad libitum weights. The colony room was continuously illuminated. These pigeons had received previous training under similar conditions (see Papini, 1997, Experiments 1 and 3). Their previous experience involved training with 1 ($n = 5$) or 15 pellets ($n = 7$); the prior magnitude assignment was kept constant in the present experiment, in which the same reward magnitudes were used.

Apparatus

Training was administered in three boxes equipped with a single pigeon key and a pellet dispenser. Each box was enclosed in a sound-attenuating chamber containing a fan for ventilation and masking background noise. Boxes were 32.2 cm wide, 29.9 cm long, and 32.2 cm high. A feeder cup made of opaque Plexiglas and measuring 4.5 cm wide, 5.5 cm long, and 4 cm high was located in the center of one of the walls, 3 cm above the floor. Noyes precision pellets (pigeon formula, 45 mg) were automatically delivered into this cup by the pellet dispenser. Directly above the feeder cup and 18.5 cm from the floor was the response key (1.8 cm in diameter). This key could be illuminated from behind with a variety of stimuli. A white key was used during pretraining sessions, whereas a white "plus" sign on a black background was used during acquisition and extinction. Diffuse illumination was provided by a lamp (GE 1820) located on the upper left corner of the same wall. A computer located in an adjacent room controlled all the events and recorded response latencies.

Procedure

The present experiment introduced a purely instrumental response-reinforcer contingency both in pretraining and training. Therefore, reinforcement was provided only whenever the response requirement valid for a particular trial was met within a certain temporal window; otherwise, the trial ended without the delivery of

food.

Approximately 20 days after the end of the previous experiment, pigeons were returned to pretraining. Each pretraining session involved 20 trials separated by a mean intertrial interval of 60 s (range: 40-80 s). All pigeons received the same reward magnitude (i.e., 1 pellet per trial) during pretraining. These animals had been exposed to extinction at the end of the previous experiment (Papini, 1997) and, thus, the key-pecking response had to be reshaped. Pretraining started with exposure to a procedure involving both Pavlovian and instrumental contingencies. In each trial, the white key-light was presented for a maximum of 6 s. After either a single key-peck response or 6 s, whichever occurred first, the key-light was turned off and a single food pellet was immediately delivered in the food cup. When a pigeon reached a criterion of two successive sessions with a probability of response equal to or greater than 0.8 (i.e., at least 16 out of 20 trials with a response), the Pavlovian component was eliminated and pretraining continued in a purely instrumental manner. The white key-light was presented for a maximum of 6 s and a single response during that interval turned off the key-light and caused the delivery of a food pellet; failure to respond within the 6 s interval terminated the trial without reinforcement. Pigeons were trained on this FR 1 schedule until the probability of response on two consecutive sessions was equal to or greater than 0.8, whereupon the FR requirement was increased by one response. This criterion was kept constant until pigeons reached a FR 10 value; in this final stage, pigeons were trained for a minimum of 5 sessions and until they met a criterion of 3 consecutive sessions with a probability of response equal or greater than 0.8. Starting with a FR 2 value, there was a maximum of 15 s to initiate responding, and a maximum of 15 s to complete the FR requirement once responding had been initiated. Failure to initiate responding or to complete the FR once responding had been initiated was followed by key-light offset; no reinforcement was delivered.

Acquisition training began the day after pigeons met the FR 10 criterion and lasted for 52 daily sessions. Each session involved a single trial. Pigeons were transported from the vivarium to the training room in their individual cages and were placed in the conditioning boxes. The start of the session was signaled by the illumination of the box. After a mean pretrial interval of 60 s (range: 30-90 s), the "plus" sign was projected onto the response key. Completion of the FR 10 requirement resulted in the immediate delivery of either 1 pellet (Group 1) or 15 pellets (Group 15). The 15 pellets were delivered in rapid

succession, at a rate of one pellet every 20 msec. Pigeons had a maximum of 60 s to initiate responding and a maximum of 60 s to complete the 10 required responses. Failure to initiate responding or to complete the FR 10 requirement within 60 s terminated the trial without reinforcement. The daily session ended with a mean post-trial interval of 60 s (range: 30-90 s), at the end of which the house light was turned off and the animal was returned to its cage. Following acquisition, there were 48 extinction sessions that were equal in all respects to acquisition sessions except that food pellets were not delivered.

A computer recorded the initial latency, or time from the onset of the key-light to the first key-peck response, and the FR latency, or time from the first to the tenth key-peck. A maximum value of 60 was assigned to both initial and FR latencies when the pigeon failed to respond in any given trial. Absolute time values were transformed to their natural logarithm (\ln) to improve normality and allow for the use of parametric statistics. Transformed latencies were pooled over blocks of 4 trials for each animal and subjected to mixed-design analysis of variance.

RESULTS

Four pigeons failed to reach the FR 10 criterion during pretraining, presumably due to the purely instrumental contingency introduced in the present experiment. Although the conditions during pretraining were not differential, these pigeons had already been assigned to the groups based on their prior experience (one to Group 1 and three to Group 15). These animals were discarded and acquisition training (one trial per day) was conducted with the remaining 8 pigeons, 4 in each group.

The main results of the present experiment are presented in Figure 1 in terms of the \ln of the initial latency (left) or FR latency (right), for Groups 1 and 15, and as a function of 4-trial blocks. Initial acquisition latencies were relatively low because these animals had been previously trained to respond to the plus stimulus. Both latency measures were higher for Group 1 than for Group 15 early in acquisition training, but they rapidly converged. Group \times Block analyses of variance for each dependent measure indicated nonsignificant effects for Group [both $F(1, 6) < 4.09$, $p > .05$], Block [both $F(12, 72) < 1.02$, $p > .05$], or their interaction [both $F(12, 72) < 1.48$, $p > 0.05$]. However, a similar analysis over the initial 5 blocks of training detected a significant

Group effect for the FR latency [$F(1, 6) = 9.12, p < 0.025$].

Extinction performance was highly differential after acquisition training with either 1 or 15 food pellets. In fact, both initial and FR latencies showed very little decrement, if any, after training with the large, 15-pellet reward magnitude during a string of 48 daily trials. Analyses of variance computed for each dependent variable confirmed these conclusions. In the case of the initial latency, there were highly significant effects for Group [$F(1, 6) = 39.15, p < 0.001$], Block [$F(11, 66) = 4.08, p < 0.001$], and for the Group \times Block interaction [$F(11, 66) = 2.60, p < 0.001$]. Similarly, the FR latency measure also yielded highly significant effects for Group [$F(1, 6) = 80.93, p < 0.001$], Block [$F(11, 66) = 3.42, p < 0.001$], and their interaction [$F(11, 66) = 4.00, p < 0.001$].

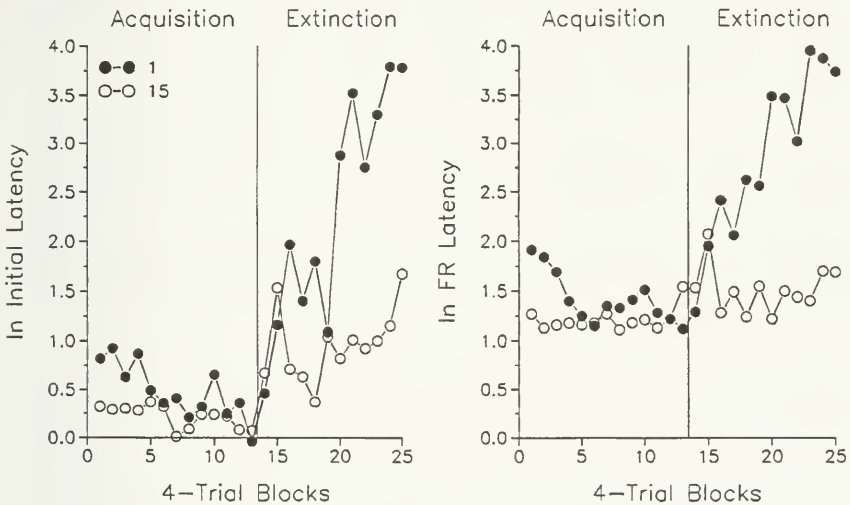


Figure 1. Acquisition and extinction of key pecking in groups of pigeons reinforced with either 1 or 15 food pellets. Initial (left panel) and fixed-ratio (FR) latencies (right panel) were transformed to natural logs and plotted as a function of 4-trial blocks. Each point represents the arithmetic mean of four subjects in each group.

Additional information was obtained from the trials in which pigeons either initiated but did not complete the FR requirement (incomplete FR), and trials in which animals did not respond at all (response failure). These results are presented in Table 1.

In the 52 acquisition trials, there were relatively few instances of incomplete FR trials, but a few more cases of response failure, although all of them in Group 1. Although not particularly strong, the evidence presented in Table 1 suggests that acquisition performance was facilitated by the larger magnitude of reinforcement under the present, purely instrumental, conditions. In the 48 extinction trials, there were clearly more instances of both incomplete FR trials and response failures in Group 1 than in Group 15. Generally, these data suggest that the effects of reinforcer magnitude on key-pecking performance are predominantly reflected in terms of response failure. Once pigeons initiate responding in any given trial, they are likely to complete the FR requirement.

Table 1. Number of trials in which pigeons failed to respond or initiated but did not complete the FR requirement. Number in parenthesis corresponds to the range for each group of four animals.

	Incomplete FR		Response Failure	
	Acquisition	Extinction	Acquisition	Extinction
Group 15	0.50 (0-1)	0.25 (0-1)	0	3.00 (0-5)
Group 1	0.25 (0-1)	2.75 (1-5)	1.50 (0-4)	20.75 (19-23)

DISCUSSION

The degree of persistence during extinction observed in pigeons trained with the large reward was remarkable. This type of persistence is typical of mammals trained under small reward conditions or of infant rats (Amsel, 1992), but not of adult rats trained under widely spaced conditions with relatively large reward magnitudes (Hulse, 1958; Wagner, 1961). These results agree with those previously reported by Papini (1997) and suggest that the emergence of nonparadoxical extinction performance is not related to the presence of a response-independent component in the reinforcement contingency implemented in the original experiments. Persistence is greater after large rewards than after small rewards whether extinction of key pecking follows training under a purely instrumental contingency (present experiment) or under a mixed instrumental and Pavlovian

contingency (Papini, 1997).

The results reported by Roberts et al. (1963), using a runway procedure, can be interpreted as inconsistent with the present data. These findings are contradictory to the extent that extinction after manipulations of reinforcer schedule and magnitude are thought to depend on the same mechanisms (Amsel, 1992). It is possible that, in the pigeon, whether extinction is paradoxical (as in Roberts *et al.*'s study) or not (as in the present study) might depend on the response system used to assess instrumental learning (i.e., key-pecking versus running responses). Although there is limited information on this issue in mammals, the operant-instrumental distinction does not appear relevant. McNaughton (1984) compared lever pressing (operant) and runway (instrumental) performance of rats given a single trial per day, finding clear evidence of the partial reinforcement extinction effect in both situations. A clarification of the role of response bias in the paradoxical performance of pigeons will require a study of the effect of partial reinforcement on extinction of key-pecking performance, as well as the effect of reward magnitude on extinction of runway performance, both under spaced-trial conditions.

Key-pecking behavior acquired by pigeons under widely temporally spaced conditions of training appears to depend entirely upon the associative strength gained by the stimulus through its pairing with rewards of various magnitudes (Bitterman, 1975). Such a simple assumption has proven inappropriate for handling the results obtained with mammals (Amsel, 1992; Daly & Daly, 1982). Further analysis of learning in a comparative framework will contribute to establishing the limits of behavioral processes thought to be general, such as the acquisition of anticipatory frustration (Amsel, 1992) or of specific reward memories (Capaldi, 1994). Although hypothetical general processes have been helpful for understanding some aspects of learning in mammals, they do not seem to be required to explain available evidence from spaced-trial experiments with a variety of non-mammalian vertebrates.

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COMPARATIVE PERSPECTIVES ON POINTING AND JOINT ATTENTION IN CHILDREN AND APES

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ABSTRACT: The comprehension and production of manual pointing and joint visual attention are already well developed when human infants reach their second year. These early developmental milestones mark the infant's transition into accelerated linguistic competence and shared experiences with others. The ability to draw another's attention toward distal objects or events facilitates the development of complex cognitive processes such as language acquisition. A comparative approach allows us to examine the evolution of these phenomena. Of recent interest is whether non-human primates also gesture and manipulate the eye gaze direction of others when communicating. However, all captive apes do not use referential gestures such as pointing, or appear to understand the meaning of shared attention. Those that show evidence of these abilities differ in their expression of them, and this may be closely related to rearing history. This paper reviews the literature on the topic of pointing and joint attention in non-human primates with the goal of identifying why these abilities develop in other species, and to examine the potential sources of the existing individual variation in their expression.

By the time they reach their second year, human children engage in social interactions that often include pointing and the establishment and manipulation of joint visual attention. The developmental course of pointing follows a relatively predictable pattern. In its earliest form, pointing is probably a self-orienting reflex or an alertness reaction, rather than an attempt to manipulate the attention of others (Bates, 1976; Hannan & Fogel, 1987; Lock, Young, Service, & Chandler, 1990; Trevarthen, 1977). The earliest form of visual orientation may be present as early as two months of age (Scaife & Bruner, 1975), with infants shifting their eye gaze in relation to an adult's gaze direction, though a specific referent is rarely the focus of the infant's attention

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(Butterworth & Cochran, 1980). At around 14 months, children point in a variety of contexts – from making requests, to calling the attention of others to objects or events. Infants who point while alternating their eye gaze between the partner of an interaction and the referent probably understand that pointing is only successful when the visual attention of another is held (Balwin, 1995). Thus an understanding that others are "intentional agents" coincides with an understanding that pointing can be used to direct the attention of others toward distal objects and events.

Comprehension of the social meaning of pointing normally precedes its production by human infants (Butterworth, 1991; Schaffer, 1984). Infants typically begin looking in the directions toward which others point at around 10-12 months of age (Leung & Rheingold, 1981; Murphy & Messer, 1977; Schaffer, 1984). Around this time, children comprehend pointing gestures and the referential nature of gaze direction as long as the referent is within their immediate visual field (Butterworth & Cochran, 1980). By eighteen months, children are capable of following the gaze direction and pointing of another toward objects that are outside of their initial visual field (Butterworth & Grover, 1988). At least three important components are involved in the production of referential pointing – the establishment of joint attention, extension of the hand and arm (typically with index finger extension) toward the object or event of interest, and concomitant eye gaze alternation between the referent and the partner in the interaction. Pointing is clearly of great importance to the development of human cognitive abilities, as pointing and joint visual attention are closely linked to, among other things, language acquisition (Bruner, 1983; Goldfield, 1990) and to developing a "theory of mind" (Baron-Cohen, 1991).

Pointing has been considered to be species-specific to humans by several authors (Povinelli & Davis, 1994; Werner & Kaplan, 1963). This is true insofar as the gesture does not appear to develop in feral non-human primates (but see Veá & Sabater-Pi, 1998, for a possible case in one wild pygmy chimpanzee, *Pan paniscus*). However, pointing and "pointing-like" gestures have been reported for all four great ape species and in some monkeys raised in various captive conditions. This suggests that, like many abilities that are revealed in laboratory studies of ape cognition, humans have a fairly pervasive influence on the animals with which they interact (see Call & Tomasello, 1996, for review). Based on the existing literature of ape pointing, there are differences in some topographical features of the gesture that may be attributable to rearing history. Captive ape conditions include

laboratory rearing in isolation or in social groups, nursery rearing where humans serve as surrogate parents for the apes' first few years, and cross-fostering, where a home-like setting and routine is provided. Most subjects of ape language studies were cross-fostered by humans (Gardner & Gardner, 1988; Miles, 1990; Patterson, 1978). The rationale for many of the early attempts to teach sign language to apes was based on the fact that they are adept at using their hands and often do so when communicating.

THE ETHOLOGY OF COMMUNICATIVE GESTURES

Feral chimpanzees have rich vocal and gestural communicative repertoires (Goodall, 1968; Marler & Tenaza, 1977; Plooi, 1978). Plooi (1978) found that some aspects of wild chimpanzee communication resemble human pre-linguistic behavior. Bates (1976) considers the use of an object to obtain someone's attention to be one type of proto-declarative communication. Human infants, for example, may repeatedly strike the ground with a toy in order to get an adult's attention. Bates, Camaioni, and Volterra (1975) define proto-declarative communication as "...a preverbal effort to direct the adult's attention to some event or object in the world" (p. 208). Proto-declarative acts eventually accompany declaratives, which can be simple forms of verbal output produced by human children for the purposes of giving or showing (Bates et al., 1975).

Plooi (1978) found examples of proto-declarative communication in feral chimpanzees. For example, chimpanzees pick leaves and manipulate them when in the presence of conspecifics. This behavior usually leads other chimpanzees to approach and observe this "leaf-grooming". The putative goal of this behavior appears to have less to do with grooming leaves, and more to do with initiating play, social grooming, or sexual interactions (Nishida, 1980). A similar example noted by Plooi (1978) involved play solicitation where a chimpanzee would grab an object (often a fairly abundant, non-valuable one such as a twig) and run away with it while looking back toward another chimpanzee. During respites in their daily ranging, Goodall (1986) observed leaders in chimpanzee groups looking toward other group members before moving to other areas, or shaking branches to initiate consortships or group movements.

Looking at the mother's face while interacting is an important development in human infant communication (Bates et al., 1975;

Butterworth, 1991; Corkum & Moore, 1995). Eye gaze direction can be used to specify the referent of an interaction and the location of an object or event. Human infants understand that the adult is an agent of an interaction when they begin looking toward their mother's face while communicating (Bates et al.). In comparison, chimpanzee infants initially grab food from their mothers when begging, but eventually communicate their wishes through indirect means such as touching the mother's mouth and looking at her face (Plooij, 1978). However, aside from Veá and Sabater-Pi's (1998) observations, pointing has not been reported in feral apes.

THE COMPARATIVE PSYCHOLOGY OF COMMUNICATIVE GESTURES

With few exceptions, reports of non-human primate pointing involve laboratory or home-reared subjects. Some laboratory rhesus macaques (*Macaca mulatta*) pointed toward objects that they were not able to reach during experimental situations. Blaschke and Ettlinger (1987) observed whole-hand pointing by four monkeys, and Hess, Novak, and Povinelli (1993) describe one monkey's gesture as "pointing-like". Rhesus monkeys also follow the eye gaze of conspecifics toward objects (Emery, et al., 1997), and Capuchin monkeys (*Cebus apella*) have shown evidence for deceptive pointing under experimental conditions (Mitchell & Anderson, 1997). In comparison to these reports, however, the pointing that has been reported for great apes appears, in many cases, to be more similar to that of human children (e.g., hand shapes used, audience effects, shared attention). However, some of the similarities bare close resemblance to non-pointing gestures used by feral apes. Thus a close evaluation of the topographical features of the pointing gesture is necessary. Also, some important contextual differences that elicit pointing in apes and children remain given the current state of knowledge. Captive apes normally point toward objects to request them. Human children do this as well, but also point for other reasons and incorporate gesture with speech. The work reviewed below compares the pointing reported for captive apes across rearing environments, and highlights some of the similarities and notable differences between ape and human pointing.

Pointing in laboratory reared, non-language trained apes

There are several reports of pointing in laboratory apes. Among the earliest is Wolfgang Kohler's discovery that chimpanzees could be trained to point toward a box containing food (cited in Yerkes & Yerkes, 1929). The majority of instances of pointing in chimpanzees are of laboratory-reared individuals (see Leavens & Hopkins, 1998, for brief historical review). During their attempts to test the abilities of chimpanzees to deceive and recognize intentions, Woodruff and Premack (1979) required four chimpanzees to communicate the location of out of reach objects to humans. The chimpanzees involved in this experiment were wild-caught and had no formal training in any mode of human-based communication. Three of the chimpanzees developed manual pointing without any explicit training from the experimenters, and one chimpanzee "pointed" with her foot. However, these four chimpanzees did not point outside of the testing situations (Premack & Premack, 1983).

Povinelli, Nelson, and Boysen (1992) report pointing by four chimpanzees during an experiment on social attribution. A contingency was arranged that required the chimpanzees to direct the attention of experimenters, who had different apparent knowledge states, toward a specific location in order to receive a reward. Pointing was among the gestures described, but the authors found that some of these gestures were akin to food begging gestures seen in wild chimpanzees (Goodall, 1968), or variations of gestures that may have resembled pointing in at least some ways. The four subjects of this study showed spontaneous comprehension of human pointing (the authors do note that the chimpanzees had previous experience with similar testing situations). Two of the subjects (Sarah and Darrell) pointed from the outset of the experiments while the others (Sheba and Kermit) eventually developed a gesture that at least resembled pointing. Of these subjects, Sarah was the only one who had received language training, and her pointing was previously reported (Premack & Woodruff, 1978).

The first experimental study of pointing in chimpanzees was that of Leavens, Hopkins, and Bard (1996). Clint, a fourteen year old, nursery-reared subject, pointed toward out of reach food with both whole-hand and indexical points. Notably, Clint also alternated his eye gaze between the food and an experimenter during the majority of the trials. Two other subjects, Flora and Anna (nursery-reared, and possibly wild caught, respectively), also pointed indexically and whole-handedly, but eye gaze direction was not measured for these two. To date, the study

with the largest sample is Leavens and Hopkins (1998), who report pointing in 53 of 115 chimpanzees tested at the Yerkes Regional Primate Center. The majority of the subjects pointed whole-handedly (88.7%), while the other 11.3% pointed indexically. Also, chimpanzees that were reared in a nursery alternated their eye gaze between an experimenter and a referent much more than mother-reared chimpanzees. Mother-reared chimpanzees did, however, look toward the experimenter while pointing. Interestingly, Leavens and Hopkins (1998) found no significant differences in pointing frequencies between nursery and mother-reared chimpanzees. Gaze alternation during social referencing also occurs among nursery-reared chimpanzees (Russell, Bard, & Adamson, 1997), with incidences of this increasing with age. There is also evidence for social referencing between chimpanzee mother-infant pairs (Evans & Tomasello, 1986; Itakura, 1995).

Call and Tomasello (1994) report pointing in a laboratory reared orangutan (Puti) and a cross-fostered, language-trained orangutan (Chantek). Comparisons between the two were made in the production and comprehension of pointing and tests for sensitivity to varying levels of experimenter visual attention were done as well. Puti's ability to use and comprehend pointing was more limited in comparison to Chantek. Also, Puti pointed regardless of whether the experimenter had his eyes open or closed, thus he did not appear to understand the meaning of visual perception or the bi-directional nature of pointing. Chantek, however, was much more likely to point when the experimenter was looking toward him. Miles' (1990) longitudinal observations of Chantek's pointing supports the notion that human exposure facilitates the development of increasingly complex sociocognitive abilities in great apes (see below). Although there are fewer reports of pointing in orangutans than for chimpanzees, additional examples have been noted in the former while performing various cognitive tasks (e.g., Call & Rochat, 1997).

To my knowledge there are no published reports of pointing in non language-trained gorillas. Gomez (1991) reports intentional communication, as measured by eye gaze alternation in a problem solving situation, but no pointing, in a young, hand-reared gorilla. Also, Tanner and Byrne (1996) found that several gestures used by a captive gorilla appeared to be iconically representative of action or movement.

Pointing in Cross-fostered and language trained apes

Published accounts of pointing exist for nearly every ape that has

been home-reared and/or received language training. These include anecdotal reports (e.g., Hayes & Hayes, 1954; Kellogg & Kellogg, 1933; Savage-Rumbaugh, 1984), descriptions of American Sign Language (ASL) hand shapes (Fouts, Hirsch, & Fouts, 1982; Gardner, Gardner, & Nichols, 1989), experimental studies (Krause & Fouts, 1997), and developmental accounts (Miles, 1990). Pointing is also reported as a mode of communication used by cross-fostered and language-trained chimpanzees while solving various problems (Boysen & Bernston, 1989; Premack & Woodruff, 1978). Unfortunately, little developmental data on pointing exist for language-trained chimpanzees. To date, the only developmental information available for chimpanzees (a cross-sectional study) is for laboratory and nursery-reared subjects (Leavens & Hopkins, 1998).

Kellogg and Kellogg (1967) raised the chimpanzee Gua in their home in order to compare her development with their son. Without any assistance from her caregivers, Gua pointed with an extended index finger shortly after the Kelloggs began their project. The Kelloggs note that "Perhaps the best indicator of 'seeing' or 'observing' on her part is the reaction of pointing with the index finger to objects which attract her attention" (p. 89). Donald, the Kelloggs' son whose development was compared with Gua's, did not begin pointing until after Gua developed the gesture. However, Gua only pointed toward objects within her reach. For example, the Kelloggs observed Gua following bugs while pointing toward them. Hayes and Hayes (1954) raised the chimpanzee Viki in their home and noted that she too pointed, but only to objects that were within her reach (such as objects that she was forbidden to touch). Unfortunately, due to a lack of descriptive information, these early reports are difficult to evaluate.

Gardner et al. (1989) provided information on the order in which ASL signs were used reliably by Washoe, Moja, Tatu, and Dar. Pointing signs were among the earliest to be used reliably by the four chimpanzees. The first sign used reliably by Tatu was GO, and Washoe's 28th reliable sign was ME. (See Gardner et al. for criteria of reliable usage), the latter of which was the latest that any pointing sign was incorporated into the sign vocabularies of the four (of around 150 to 200 signs each). Gardner et al. described the chimpanzees' hand configurations for the sign THAT/THERE as "Index extended" for Tatu and Dar, and as "Index extended from open hand or open hand" (p. 157) for Washoe and Moja. Fouts, Fouts, and VanCantfort (1989) describe Loulis' THAT/THERE sign as "Tip of index contacts or points toward object or location" (p. 289). Notably, Loulis learned some signs from

other chimpanzees (Fouts, Hirsch, & Fouts, 1982). It should be noted that the above descriptions are of the appearance of signs as they are normally used. The goals of each of these studies were not to estimate the relative frequencies of any variations in the place, hand configuration, or movement of the signs. Krause and Fouts (1997), however, provide relative frequencies of index and whole-hand pointing in Moja and Tatu during two experiments – taken together, index finger extension was scored for 364 of 416 (87.5%) points, and the remaining 12.5% of points were whole-handed.

The indexical signs (e.g., THAT/THERE) of language-trained chimpanzees are consistently used in a structured order (Gardner & Gardner, 1975, 1994). Moja, Tatu, and Dar used the THAT/THERE sign prior to noun signs when producing nominative phrases (e.g., THAT BRUSH) in reply to the question WHAT THAT? In response to locative queries (e.g., WHERE BRUSH?), the three typically followed the noun with the indexical sign (e.g., BRUSH THERE) (Gardner & Gardner, 1975, 1994).

Terrace (1987) also described the hand configurations of his language-trained chimpanzee Nim, who used the indexical signs YOU, ME, THAT/THERE, and GO. Terrace later combined these into a single "point" sign. Nim's first reliable pointing sign was GO (his 14th overall), which Terrace (1987) described as "flat hand, palm down; sometimes index finger extended from loosely cupped hand". Nim's second reliable pointing sign was ME (28th overall), which took the form of a flat hand in its original form, and at the termination of the project was described as "index finger extended from closed fist". Nim's 43rd reliable sign was YOU and his 49th sign was THAT/THERE. The hand shapes for both of these were described as "index finger extended from closed fist", with "palm in various orientations" added to the hand shape description of the latter. Nim used signs that involved index finger extension before his first pointing sign was acquired (e.g., LISTEN). That Nim's first pointing signs were whole-handed, and his later ones indexical, suggests that indexical pointing may have developed from whole-hand pointing (which is not the case for human infants). Laura Pettito, a former teacher of Nim, maintained that "apes...do not point to a referent while moving eye gaze to and fro between the referent and the caretaker to establish joint visual regard" (1988, p. 216-217). At the time this quote was published, there was no experimental evidence that could address this assertion. Therefore, based on Pettito's observations, it appears that Nim did not point communicatively. Terrace and his colleagues never published any

experimental evidence to support or refute the claim.

Boysen, Berntson, Shreyer, and Hannan (1995) described various "indicating acts" used by Sheba during experimental tests of numerical competence. Sheba was cross-fostered for her first 2.5 years, and had extensive direct contact with human caregivers. Pointing was among the gestures used by Sheba (at nine years of age) in Boysen et al., and her use of pointing prior to this had been noted (Povinelli, Nelson, & Boysen, 1992). Figure 3 in Boysen and Berntson (1989) shows Sheba "motor tagging" objects in an array, which is a gesture that is akin to pointing and is typically used by Sheba during tests of numerical competence.

Miles (1990) reports the development of referential communication in the orangutan Chantek. Miles (1980) taught Chantek to use ASL while rearing him in a home-like environment. Chantek acquired 140 signs over the course of the project, some of which were pointing signs (Miles, 1990). Chantek pointed to refer to himself at 13 months of age, and by 29 months pointed to indicate the direction of locations. Chantek also alternated his eye gaze between the referent and his conversation partner when pointing (Miles, 1990). Pointing signs were also reported for Princess, a home reared/free ranging, language-trained orangutan (Shapiro, 1982), but information on eye gaze and hand shapes were not provided.

BUT IS IT POINTING?

The similarities between the natural food-begging gestures of feral chimpanzees and the pointing of captive chimpanzees deserve attention, especially since the majority of studies where pointing is reported included food that could not be obtained without the assistance of a caregiver. Goodall (1968, 1986) and Plooij (1978) noted that while food begging the palm faces upward and is held out toward the mouth of the possessor of the food. Thus it is possible that chimpanzees reared in captivity are simply using some variation of this gesture, rather than pointing. In terms of hand shape, both food begging and pointing differ in at least two important ways. First of all, food-begging gestures are often prolonged, where the supinated hand remains in the proximity of the mouth or hands of the possessor. Secondly, when pointing the palm is normally oriented either toward the ground, or at a right angle to the ground. All digits are normally extended when food begging, which can be true for pointing as well (although indexical pointing is more

common among humans). A conservative distinction between pointing and non-pointing can be made wherein pointing that occurs when no putative goal is present is not food begging (or begging of any other sort). When food is present, however, a close examination of hand shape is necessary in order to distinguish points from food begs.

Feral chimpanzees that food beg are typically in very close proximity to the possessor of the food. It is possible (although not always probable) that a begging chimpanzee could easily grab food from its possessor. Barriers such as cage mesh or plexiglas often prevent captive chimpanzees from obtaining food themselves, which is a situation that most chimpanzees for which there are reports of pointing encounter. This by itself does not preclude the possibility that gestures are food begs rather than points. However, food-begging gestures can resemble manual reaching. In humans, pointing does not appear to develop out of failed attempts to grasp objects, yet it has been hypothesized as ontogenetically rooted in reaching for the purpose of touching, rather than grabbing (Werner & Kaplan, 1963). Vygotsky (1926/1962) viewed pointing as exclusively instrumental, serving to connect the infant with the physical world and is thus simply a modified form of reaching. In contrast to this, Franco and Butterworth (1996) recently found concomitant development of reaching and declarative pointing. Regardless of its developmental course in humans, we can not simply assume that any of these findings hold true for the development of pointing in great apes, especially since it does not appear to occur naturally (but see Veá & Sabater-Pi, 1998).

Presumably, if chimpanzees are motivated enough to reach for food, it would be consumed immediately should the possibility to obtain it without assistance arise. Since many of the pointing gestures used by chimpanzees are whole-handed, audience effects can also be used as a criterion to distinguish reaching from pointing. If gestures or directed hand and arm movements of any kind orient toward out of reach food (in the absence of caregivers), we might conclude that the gestures are attempts to reach the food. However, this occurred only twice out of 256 points among the three chimpanzees observed in Leavens et al. (1996). In Krause and Fouts (1997), the two chimpanzees waited for a human to face them directly before pointing in 99% of their trials. Pointing toward out of reach food without the visual attention of a caregiver could also reflect an inability to comprehend the importance of shared attention, even if the gesture itself appears more pointing-like than reaching-like. Thus shared attention and pointing or "pointing-like" (non-reaching) gestures together serve to distinguish

intentional, communicative acts from non-communicative reaching or grasping.

In its most basic form, communicative pointing requires an understanding that certain sensory stimuli are encoded via the visual modality in both the sender and the recipient of the gesture. Many language and non-language trained apes appear to understand this, as pointing is less likely to occur when there is no mutual eye contact. Recently, however, Povinelli and Eddy (1996) discovered a failure to spontaneously recognize that "seeing is knowing" in seven young (4 to 6 years old), laboratory-reared chimpanzees. In other words, the chimpanzees showed no automatic preference to food beg from an experimenter that was looking toward the chimpanzee, versus one with his or her vision obstructed to varying degrees (although performance increased over time). This contradicts what has been discovered in the studies of audience effects and pointing reviewed above. Call and Tomasello (1994) manipulated the attention levels of the experimenters and found comprehension by their language-trained subject. Krause and Fouts (1997) and Leavens et al. (1996) figured audience effects into their designs but did not vary the levels of the experimenter's visual attention when present. Regardless, the chimpanzees from these two studies rarely pointed unless a human was present and looking toward them. Tomasello, Call, and Hare (1998) recently discovered conspecific gaze following in five monkey and apes species, which further demonstrates that nonhuman primates use the gaze direction of others to obtain information.

That certain apes do not understand the link between seeing and knowing does not preclude investigations of pointing and shared attention in non-human primates, nor does it negate any previous findings demonstrating positive results. Manipulating experimenter attention levels is a necessary procedure for establishing whether chimpanzees and other apes communicate intentionally. Furthermore, careful analyses of hand shapes serve to determine whether gestures are points, food begs, or reaches.

HAND MORPHOLOGY: IMPLICATIONS FOR POINTING

Povinelli and Davis (1994) contend that "...chimpanzees ... do not develop a pointing gesture with the index finger and rarely point by gesturing with hands or arms" (p. 134). This certainly is not true for all captive chimpanzees. Povinelli and Davis' (1994) explanation for the

purported lack of pointing in chimpanzees is based on the resting state of the hand. At a resting state (wrist pronated and fingers relaxed), the index finger of the human hand normally protrudes slightly above the remaining fingers, whereas the chimpanzee hand curves with all digits (besides the thumb) positioned parallel to each other. Povinelli and Davis (1994) consider this a possible explanation that supports their position that chimpanzees do not point, and "...suspect that the species differences ... obtained are due to differential tenodesis action of the extensor digitorum in the index finger of humans and chimpanzees..." (p. 138). The authors go on to state that "...in the present context the exact nature of the morphological difference is secondary to its behavioral expression" (p. 138). Actually, the morphological difference may be of primary importance as an explanation for the relatively low incidences of indexical pointing in chimpanzees. Evidence for behavioral expression has existed for quite some time now.

Treating the shape of the pointing hand with such primacy may undermine the actual importance of the gesture, which are its functional properties. This has been noted with regard to human infant pointing (Blake, O'Rourke, & Borzellino, 1994). Information is not necessarily lost when the whole hand is used for pointing -- the intentions of the gesturer are still communicated. On the other hand, if gaze following or audience effects were absent, there would be a significant breakdown in communication. Still, in considering hand configuration alone, the pointing of many language-trained chimpanzees is more similar to that of humans than of non-language trained chimpanzees. This may be because their hands are physically molded into the appropriate hand shape while they are learning the gesture (Fouts, 1972), or because direct observation is encouraged as a means to acquire signs. The teaching and use of non-pointing signs that include index finger extension may also serve to facilitate the development of indexical pointing.

Butterworth (1991) hypothesizes that "The specialized function of the index finger in relation to shared attention may be innate" (p. 230). He also suggests that the relationship between the human thumb and index finger is a specialized adaptation, perhaps relating to precision gripping and tool manufacture. The opposability of the human thumb and index finger, which allows one to form a pincer grip, may have implications for pointing. Butterworth (1998) takes the position that "Perhaps the question whether chimpanzees point should no longer be expressed simply in terms of whether the ability is present or absent. The more appropriate question is why index-finger pointing is

relatively infrequent and very difficult to observe in chimpanzees" (p. 179). Butterworth (1998) hypothesizes that the pincer grip co-evolved with pointing, although with different respective functions. Human infants use pincer grips by 15 months of age and do so consistently from the time of onset (Butterworth, Verweij, & Hopkins, 1997). Chimpanzees also use the pincer grip, but it develops much later and occurs less frequently (Butterworth & Itakura, in press; Jones-Engel & Bard, 1996).

According to the Butterworth (1998), pointing is the motor antithesis of the pincer grip, and the two hand configurations serve antithetical functions. The pincer grip involves the fine manipulation and control of tools or objects, while pointing involves the manipulation of the outward attention of another (Butterworth, 1998). Thus, the precision afforded by index-thumb opposability may explain some of the differences between ape and human pointing. Another explanation for the predominance of indexical pointing in language-trained apes may be found if the development of pincer grips are described for these subjects. Evidence from Christel (1995) suggests that manual precision among primates relate to species capacities for shared attention. This relationship could be further evaluated by examining the effects of rearing environment (e.g., language versus non-language training) on the concomitant development of manual gripping and pointing. Comparisons with tool-using, feral chimpanzees would be quite valuable.

SOCIAL CONTEXT AND POINTING

Using criteria set forth by researchers of child development, the descriptions of captive ape pointing suggest that the gestures are intentional. The majority of studies of pointing and shared attention in primates show strong evidence of "imperative" pointing, the function of which is to draw the attention of another toward him or herself, and, to redirect the recipient's attention toward something desired. Declarative pointing, on the other hand, functions to redirect the attention of another toward something for the purposes of sharing or showing (Franco & Butterworth, 1996; Tomasello & Camaioni, 1997). This implies that the organism recognizes that the recipient has states of knowledge, emotion, and/or belief, which there is some evidence for in chimpanzees (Premack & Woodruff, 1978; but see Heyes, 1998).

There are some examples of declarative communication and

pointing in non-human primates (Gardner & Gardner, 1975; Miles, 1990; Patterson, 1978; Russell, et al., 1997; Savage-Rumbaugh, 1986, 1988). Most of these instances come from subjects who were language trained and thus had extensive exposure to human pointing. However, apes that point appear to primarily do so in imperative contexts. In every systematic study of ape pointing published to date, an object of some kind (food or a tool used to obtain food) was placed out of the subject's reach. Declarative pointing is probably rare among apes, even those raised by humans in socially enriched environments. This may simply be because apes rarely need to show things to others in these situations, or only do so when verbal or signed questions (e.g., WHAT THAT?) posed by humans, precede the pointing (e.g., Van Cantfort, Gardner, & Gardner, 1989).

One type of pointing that clearly is not imperative has been reported for language-trained chimpanzees. Language-trained chimpanzees sign to themselves when no humans are present (Bodamer, Fouts, Fouts, & Jensvold, 1994). Furrow's (1984) categories of private speech were used to score chimpanzee private signing in 56 hours of videotape reported in Bodamer et al. Among these categories was "referential", which was defined as "an utterance (that) refers to a present object or a present event that does not involve the child" (Furrow, 1984, p. 358). Pointing is a referential act that typically takes place in a social context. Defining it otherwise runs counterintuitive to what has become a broadly accepted definition of referential pointing; but in the interest of comparing private with social speech, a common definition is needed. The chimpanzees in Bodamer et al. often pointed while private signing. While this is not referential (or declarative) in the standard usage of the term which implies outward social communication, it is another interesting context in which, at least, pointing that is not imperative occurs.

CONCLUSION

The development of both human and ape social cognition begins early. Given this, comparative studies of social cognition ought to treat rearing conditions as a set of variables that are inextricably linked to performance. The development of chimpanzee muscle tone and social responses are affected by their early rearing environments, with differences becoming evident even within the first month of life (Bard & Gardner, 1996). Rearing environment appears to have a greater effect

on temperament than on cognition in one-year old chimpanzees (Bard & Gardner, 1996). However, cognitive skills in chimpanzees and other apes may develop more slowly than in humans, and the effects of cultural influences on the expression of ape cognition may be delayed in comparison to human infants. Therefore, the effects of rearing environment on social cognition may not be apparent until late infancy, adolescence, or adulthood.

Issues in need of attention in research on pointing in non-human primates include the topographies of the gestures used, gaze direction, and the social contexts in which it occurs. The first two have received considerable attention in the experimental work reviewed above. The third, social context, has received less attention largely because it is difficult to distinguish such phenomena in non-linguistic species, and because it may occur only rarely. Imperative pointing appears to be fairly common among captive apes reared under various conditions, which makes it especially important that pointing be distinguished from food begging or reaching. The convergence of this behavior among captive apes may stem from a context that is common to most captive environments. Human caregivers typically control resources such as food and other objects that captive apes are known to request. This is a partial explanation as to why many captive chimpanzees point imperatively. However, contexts that do not involve such situations exist as well, especially among cross-fostered and language-trained apes. Still, declarative pointing for these subjects is probably rare; which could be due to either cognitive differences between humans and apes, or because an appropriate eliciting context has not yet been provided in a systematic way.

Why don't feral chimpanzees point? Menzel (1973) suggests that they simply do not have the need to because they point with body posture. Similarly, Goodall (1986) notes that body orientation is used to communicate direction of travel. Also, it may be that left to their own devices, feral chimpanzees do not utilize the gesture because of cognitive limitations. Human "enculturated" apes show some cognitive capabilities that have few observed counterparts in feral populations (for further discussion see Call & Tomasello, 1996, and Tomasello & Call, 1997). However, as previously discussed, Plooij (1978) showed that some of the requisite abilities for pointing exist in feral chimpanzees, and make their appearance early in development. Thus the pointing of captive chimpanzees is superimposed upon an already existing propensity for intentional communication.

As Povinelli and Eddy (1996) point out, older chimpanzees (greater

than five years of age) may be capable of understanding the relationship between seeing and knowing, and some evidence for this appeared in a follow up study. Whether apes can or can not understand what "seeing" is may depend upon the social experiences of the individuals tested. Povinelli and Eddy (1996) researched nursery-reared chimpanzees. The social richness of chimpanzee nursery environments surely are not the same as those of human mother-infant pairs. Yet in a comparative psychological study such as this, attempts to replicate the rearing histories of the subjects ought to be made. Throughout their monograph, Povinelli and Eddy (1996) contrast mentalist hypotheses of seeing with behaviorist hypotheses, the latter of which best explains their data. Yet with no comparative data on children encountering their first contingencies of the exact type arranged in their study, we can in no way conclude that children do not learn that "seeing is knowing", as opposed to executing this knowledge spontaneously via complex mental processes. A suitable comparative base might come from cross-fostered chimpanzees. Future work in this area will hopefully be conducted.

Most studies of human pointing are from a developmental perspective. Unfortunately, few longitudinal studies of pointing exist for non-human primates. A comparative developmental base would prove invaluable for research on this topic. The relative contributions of molding and observational learning necessary to shape predominantly indexical pointing in language-trained apes are of definite interest. The developmental relationship between production and comprehension of pointing should be investigated as well. Also, surfaces such as cage mesh should be altogether removed from experimental situations. This would make tests for contrasting hypotheses (e.g., pointing vs. reaching or food begging) easier to execute and would be feasible with young subjects. Systematic observations and descriptions of other gestures used by young chimpanzees should be made as well. Among other reasons, this would allow investigators to determine if pointing is a ritualized variant of some other gesture. Also, since pointing does not occur in feral apes, we can not assume that its developmental course is similar to that of humans. Specifically, it would be worth determining if pointing develops from reaching, grasping, or touching. These hypotheses have been considered for human infants (Vygotsky, 1926/1962; Werner & Kaplan, 1963), and should be tested on non-human primates as well.

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